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LIGHTWEIGHT PILOT HELMETS: THE ISSUE OF WEIGHT VERSUS PROTECTIO--ETC(U)
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Lightweight Pilot Helmets: The Issue of Weight Versus Protection

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LIGHTWEIGHT PILOT HELMETS: THE ISSUE OF WEIGHT VERSUS PROTECTION

A thesis presented to the Faculty of the U.S. Army
Command and General Staff College in partial
fulfillment of the requirements for the
degree

MASTER OF MILITARY ART AND SCIENCE

by

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The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

ABSTRACT

This study addresses the problem of reducing the weight of pilot helmets while retaining relevant protective qualities. Existing helmet development standards are synthesized and compared in light of compatability, objectivity and standardization. The issue of decreased protection, as a result of weight reduction, is discussed in view of pilot opinion, accident experience, contemporary research and recent compromises in helmet development.

The investigation reveals distinct ambiguities in helmet development standards and incongruities between standards. The study recommends the deletion of penetration standards since they are incompatible with impact standards and prevent industry from using new materials to achieve light weight. Further, the study proposes a change to military specification MIL-H-83147 (USAF) that reflects the deletion of penetration standards and recognizes current technological developments.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Continuous advancements in the performance of tactical fighter aircraft have caused significant increases in the physiological demands upon the pilots who fly them. Sustained g loading forces the pilot to wage a losing battle against blood pooling in his extremities (causing grayouts and blackouts) as the weight of his body and personal equipment is increased six to eight fold. The reason for this is the capability of our latest high performance fighters to sustain and accelerate through high turn rates and g loading. As a result, pilots routinely experience six to eight g sustained turns in the accomplishment of their daily training missions. The average male head weights approximately 90-120 pounds under these g forces. The addition of a five pound helmet increases that weight to 120-160 pounds. Any displacement of the head from the normal upright position, such as looking down into the cockpit, renders the pilot physically unable to erect his head. Unfortunately, pilot personal equipment has not kept pace with aircraft performance.

Efforts have been made to alleviate some of the physiological problems. Two principle examples include Head Up Displays and thirty degree reclined ejection seats; however, little effort has been devoted to reducing the weight of the helmet. Tactical Air Command (TAC) has demonstrated varying degrees of interest in the development of a lightweight helmet. In 1970, TAC established a Required Operational Capability (ROC) for a lightweight helmet but did not vigorously pursue

its development. With the delivery of the F-15 aircraft, pilot experience has confirmed that the lack of a lightweight helmet has an adverse impact on operational capability. As a result, TAC issued a revised ROC (16-72) in 1972 and the testing of new helmet designs was renewed. However, the procurement of a new lightweight helmet is still unresolved, and the growing magnitude of the problem has caused the Tactical Air Warfare Center (TAWC) to place the lightweight helmet problem as a priority readiness issue for resolution in fiscal year 1979.

STATEMENT OF THE PROBLEM

The problem is to reduce the weight of pilot helmets and retain an acceptable level of protection. The central issue that has developed from attempts to solve this problem and procure a lightweight helmet for high performance jet aircraft pilots is weight versus protection. Many authorities believe that for a given material, a weight reduction equates to a decrease in protection, and they have simply been unable to agree on the amount of decreased protection they are willing to accept as a consequence of weight reduction.

PURPOSE OF STUDY

Current helmet safety protection standards are confusing and based on unrealistic performance requirements. The author will analyze these standards and evaluate them in light of accident experience, design philosophy and test methodology. This research effort will conclude with specific recommendations regarding development standards for lightweight helmets.

ASSUMPTIONS

1. There will be a continuing requirement for pilots operating high performance jet aircraft to wear a hard-shell protective helmet.

2. The helmet will continue to be the medium for attachment of the oxygen mask, communications earphones and microphone, and an integral visor. With the exception of the oxygen mask, items attached to the helmet form an integral part of the helmet and are considered part of the helmets basic weight.

3. All helmets discussed in this paper have the basic same design.

METHODOLOGY

The author will evaluate the standards, design philosophy and test methods for pilot helmets through historical research. The libraries of the Tactical Air Warfare Center, and the Defense Documentation Center provided most of the test and evaluation reports and unpublished position papers. Through the US Army Combined Arms Combat Development Activity, access to the Life Sciences Laboratory, Fort Rucker, Alablama provided valuable data concerning current helmet research. The statistical data concerning US Air Force accident experience was obtained from the Air Force Inspection and Safety Center.

Chapter II presents a matrix of applicable military and civil helmet protection standards and compares significant differences to emphasize points germane to this thesis.

Chapter III discusses lightweight helmet issues and problems.

Chapter IV contains conclusions, recommendations and areas requiring further study.

CHAPTER II

APPLICABILITY OF STANDARDS

Existing standards for evaluation of head protection are tabulated in Figure 1. It should be noted that only two of the six standards are specifically applicable to aircrew members. However, the similarities among these standards have been widely accepted as applicable to all forms of head protection. The non-military institutions shown in Figure 1 were commissioned and funded by the US Government to conduct the requisite research and provide an industrial manufacturing standard for head protection equipment. Since these standards closely parallel the needs of aircrew members, the military has shown an increasing tendancy to adopt them. The most pronounced of these is the July 1978 publication of US Navy military specification MIL-H-85047(AS) that virtually adopted the standards of the American National Safety Institute (ANSI) in its entirety. British Standards 2001 for Royal Air Force (RAF) aircrew members were initially established for motorcyclists and are included for comparison purposes.

IMPACT TEST METHODOLOGY

To establish a basis for comparison it was necessary to understand the methods by which helmet candidates are evaluated. There are two common methods of testing helmets for impact energy attenuation--dropped (sometimes known as rigid anvil) or swing-away.

Dropped Method

The dropped method involves a relatively hard headform constructed from an alloy or hardwood that simulates the contour of the head. (See Figure 3.) An accelerometer is mounted inside the headform, parallel to the point of impact and the test helmet is fitted to the headform. The helmet assembly is then lifted to a designated height and dropped onto a rigid anvil that may vary in shape from flat to a sharp cone. (4:2)

Swing Away Method

The swing-away method uses an instrumented headform and helmet assembly identical to that used in the dropped method except that the headform is attached to a jig at the lower end of the neck. (See Figure 4.) The headform is oriented on the jig so as to form the verticle axis, appearing much like balancing the helmet on a stick. The jig is designed to allow the helmet assembly to rotate at the neck attach point so that impacts to the hatband region may be evaluated. The jig and helmet assembly is then attached to a rigid jig or bench by a fragile shear pin. The dropped mass may vary in weight and shape to conform to expected impact surfaces. When the dropped mass strikes the helmet assembly, the shear pin breaks from the impulse and the helmeted headform swings-away from the jig. (4:2)

Anvils

Anvils employed by the methods described above are either flat or hemispherical and made of steel that has been polished smooth. Figure 1 includes the weight of the anvil when it is used as an impactor in the

swing-away method to determine the kenetic energy imparted to the helmet shell at impact. The weight of the anvil is not important when using the dropped method.

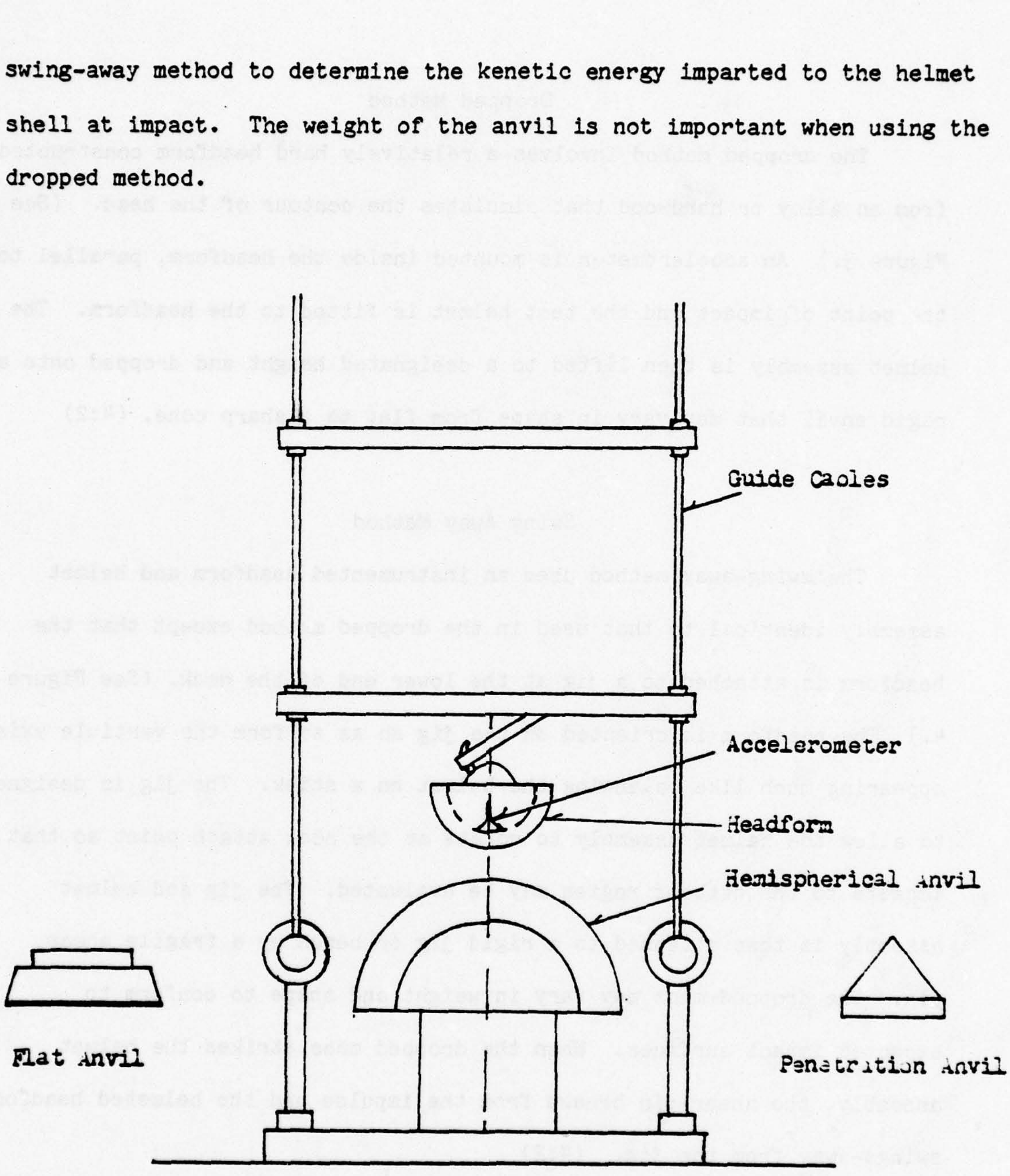

Figure 3 : Test Setup for Dropped Method Showing Flat and Hemispheric and Penetration Test Anvils (10:36)

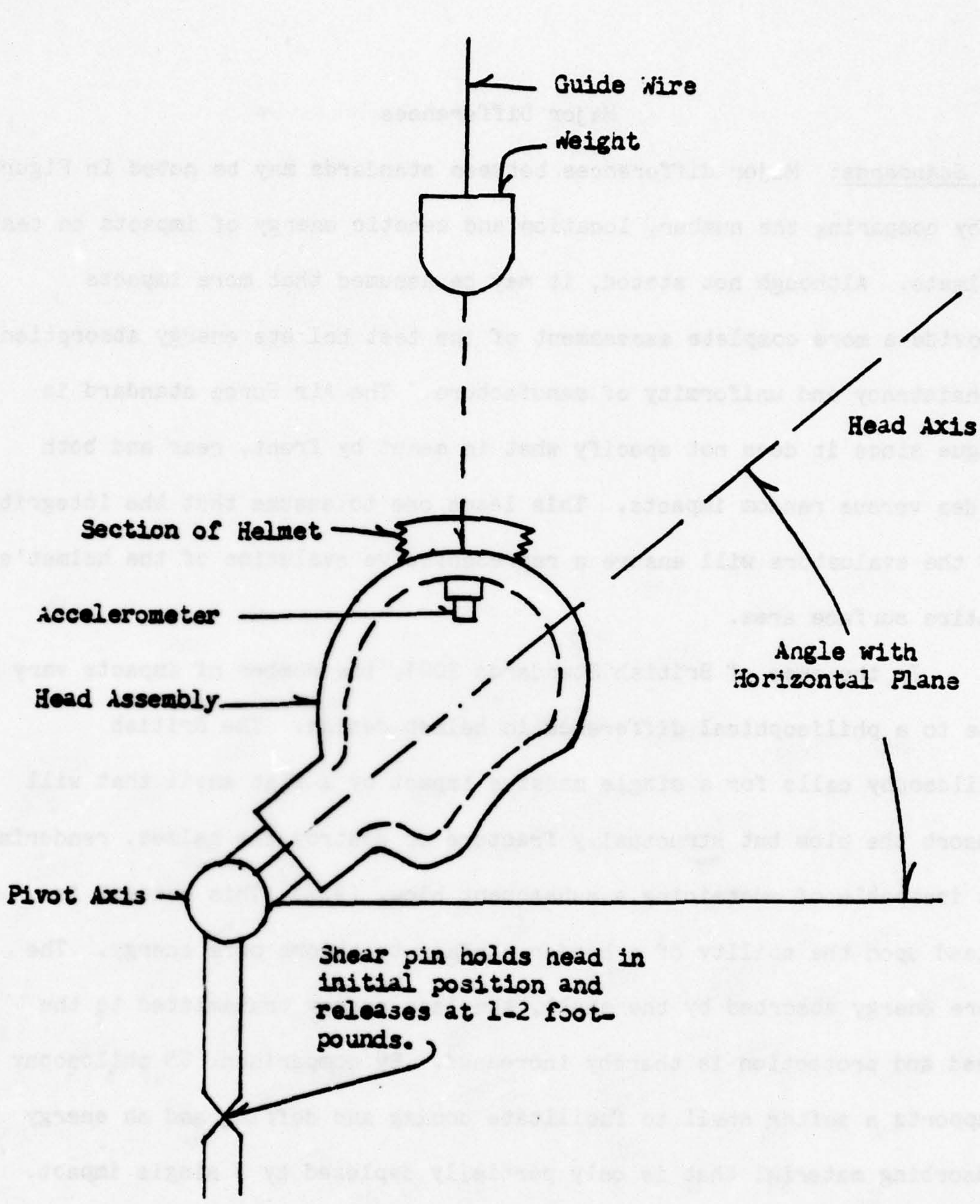

Figure 4 : Swing-Away Helmet Impact Test Apparatus (15:12)

Major Differences

In Standards: Major differences between standards may be noted in Figure 1 by comparing the number, location and kenetic energy of impacts on test helmets. Although not stated, it may be assumed that more impacts provide a more complete assessment of the test helmets energy absorption, consistency and uniformity of manufacture. The Air Force standard is vague since it does not specify what is meant by front, rear and both sides versus random impacts. This leads one to assume that the integrity of the evaluators will ensure a representative evalution of the helmet's entire surface area.

In the case of British Standards 2001, the number of impacts vary due to a philisophical difference in helmet design. The British philosophy calls for a single massive impact by a flat anvil that will absorb the blow but structually fracture or destroy the helmet, rendering it incapable of sustaining a subsequent blow. (9:2) This concept is based upon the ability of a harder surface to absorb more energy. The more energy absorbed by the shell, the less energy transmitted to the head and protection is thereby increased. By comparison, US philosophy supports a softer shell to facilitate doning and doffing and an energy absorbing material that is only partially depleted by a single impact.

Wide variations and confusion between standards underscores their artificiality. Of significant importance are the differences shown in Figure 1 between headform weight, drop height, and impact kenetic energy. Although each is independent, they are at the same time interdependent. The weight of the headform is significant when employing

the dropped method because the weight of the headform will affect the kenetic energy of the impact as it varies in height. The US Air Force standard is particularly ambiguous. It requires a small, medium or large headform of unspecified weight to be dropped from 1.83 meters (6.1 feet) exerting a force of 134.84 J (100 foot pounds). However, variations in the weight of the headform will cause corresponding variations in impact force since the helmet assembly is hoisted to the same height for each test. Another similar dichotomy exists in the American National Standards Institute (ANSI) Z-90.1A standard when the weight of the headform is fixed at 5 Kg (11.1 lbs). In this case, the drop height varies between methods and by anvil type, resulting in different impact forces for each of four alternatives. These kinds of dissimilar testing standards result in helmet candidates that have dissimilar protective qualities. Current helmet pass/fail standards are dated and incomplete. With the exception of the Snell Memorial Foundation, the helmet pass/fail stardards are generally accepted as not more than 400 instantaneous g's. The 400g standard is based upon a series of studies conducted by Dr. E. S. Gurdjian in 1962 (21:111-114), which established that a force exeeding 400g would cause a fatal concussion. Since Dr. Gurdjian's research, continued investigation into head injury has shown that the duration (time) of a force exerted on the head will significantly affect the degree of injury. As a result, there has been increasing acceptance of a graduated scale that relates impact force to the time duration required to produce brain damage (9:1). For example, a deceleration force of 400g is acceptable provided it does not exceed 2 milliseconds. Similarly, a

force of 200g cannot exceed two to four milliseconds and if the time exceeds four milliseconds the force must be 150g or less. This established a more exacting standard, increased protection and insured helmet attenuation was adequate throughout the spectrum of possible brain injury.

In Methodology: In addition to the major differences between standards, there is an inherent difference between the dropped and swing-away methods that adds still another dimension to helmet evaluations. Since the dropped methodology requires the helmet assembly to be dropped from a prescribed height, the weight of the test helmet (unlike the swing-away method) contributes to the impact energy and penalizes a heavy helmet (9:2). This characteristic may appear to be desirable in an effort to reduce helmet weight and eliminate from consideration those helmets whose weight contribute to its increased impact energy. However, this causes large helmets to be stronger and heavier (thicker shell) which forces pilots with large heads to wear heavier helmets than their counterparts. In consideration for the greater inertia of a heavy helmet, existing USAF test methods are considered by the author to needlessly compound the weight problem of a aircrewman with a large head. A greater degree of objectivity and standardization could be achieved by adopting a standard weight and force for all headforms and allow drop height to vary as necessary. The Navy specification eliminated numerous ambiguities by specifying the method, anvil, impact site, number and impact energy from the ANSI alternatives.

PENETRATION TEST METHODOLOGY

Penetration testing is conducted to determine the hardness of the helmet outer shell and to ensure that a sharp object will not penetrate the shell and deliver a lethal blow to the head. The test methodology is similar to the dropped method of the impact test; however, the anvil is conically shaped with a sharp point. Figure 2 specifies the penetration standards and describes the shape, weight and hardness of the anvils.

Although the test methodology, shape and hardness of the anvils are standardized between the US Navy and civil institutions, the anvil weight, impact energy and pass/fail standards vary considerably from USAF specifications.

Major Differences

As in the case of the impact test, helmet candidates that meet these standards have dissimilar protective qualities. A variation between standards may be noted in impact location. To ensure shell integrity and uniform thickness, USAF tests require an impact in each sixty degree sector around the helmet. However, US Navy, ANSI and Snell standards require only two impacts. Since the British Standards do not specify a number, it may be reasonably assumed that a single impact would meet the criterion. Although the British Standards constitute a significant difference from American standards, it should be kept in mind that this standard is compatible with the basic English philosophy discussed previously.

The energy of the impact varies considerably among the institutions. For example, helmets designed for motor vehicle users or motor cyclists were designed to protect against hazards frequently encountered in vehicle accidents which are different from those encountered by pilots of high performance aircraft. In addition, helmet weight is not a significant limitation to vehicle operators since the effective weight of the helmet is constant, and not subject to variations in acceleration g. As a result, the helmet shell may be varied in thickness and density to withstand greater penetration forces without regard to weight--a flexibility that is incompatable with pilot helmets due to acceleration (g) constraints. Herein lies one of the basic problems with pilot helmet criteria--the lack of compatibility of impact versus penetration criteria and the justification for each as they apply to the requirement for pilot head protection.

CHAPTER III

PROBLEMS AND ISSUES

When conducting research into protective headgear standards, one inevitably must ask the question: What purpose is a helmet supposed to accomplish? A survey of available literature revealed two documents that attempted to answer the above question. The NATO Advisory Group for Aerospace Research and Development defined the protection aspect of the helmet.

> "When an unprotected head is struck by a solid object, a very high peak force is transmitted to the skull and brain, but this force lasts for a very brief time, one millisecond or less. If the head is protected by a helmet which incorporates an energy absorbing system, ... then the impact is prolonged and the peak force developed is reduced. Protection is attributed to this reduction in peak force.... Finally, the helmet shell acts to spread localized loads by resisting penetration by sharp objects." (9:1)

The second document, Statement of Work for Aircrew Helmet Assembly, attempted to define the purpose of the helmet in terms of its required characteristics:

> "... a helmet assembly that will optimize the characteristics of weight distribution, stability, cockpit head mobility and vision and maintain these characteristics throughout the mission. Essential performance requirements shall include:
>
> a. low weight
> b. high stability
> c. impact/penetration protection
> d. unrestricted vision
> e. comfort
> f. communications
> g. CW/flashblindness/laser protection" (23:2)

The above definitions when taken in aggregate appear to credibly answer the question of what a helmet is supposed to do. However, it must be kept in mind that changes in helmet characteristics give rise to debate among pilots concerning the need or utility of a given characteristic. Recently, considerable debate has arisen over Air Force efforts to develop a helmet that would accomodate all foreseeable future needs.

PILOT OPINION

In recent years pilots have become increasingly vocal concerning their views on the requirements for protective headgear. This dialogue has been primarily responsible for the current effort to obtain a lightweight helmet and has generated an awareness of helmet problems within the Department of Defense (DoD). Pilot opinions are based primarily upon their perceptions of the tradeoffs between those helmet characteristics that provide protection and those that enhance mission accomplishment. If there is a tradeoff, most pilots lean toward mission accomplishment--accepting decreased protection as an inherent risk of piloting high performance fighter aircraft. Their acceptance of risk is rooted in the concept that if the helmet does not hinder the pilot's operation of the aircraft, the probability of being defeated is reduced. Similarly, if the pilot is not defeated, his need for the protective aspect of the helmet is also reduced. Researchers T. D. Dunham and M. A. Sissung confirmed these beliefs during their aircrew protective headgear study in 1971.(5:69-80) In their report, 51 fighter pilots were surveyed for their opinions about eight situations and the likelihood of incurring

a head impact while properly restrained. Their responses for five of the eight situations in the order of likelihood follow:

TABLE 1

SITUATION	LIKELIHOOD (%)		
	Unlikely	Likely	Inevitable
1. Crash landing/ditch or parachute landing	9.8	70.6	19.6
2. In-flight egress	32.7	57.1	10.2
3. Loss of aircraft canopy	41.2	47.1	11.7
4. Weather turbulence	43.1	53.0	3.9
5. Aircraft buffeting	62.7	35.3	2.0

It is evident from this study that pilots believed the most likely condition resulting in a head impact would be associated with a catastrophic emergency involving aircraft abandonment. Aircraft abandonment is relatively rare for US aviators and then most often associated with fire, explosion or loss of control. When compared to the total number of hours flown, the probability of any pilot abandoning an aircraft is so low that pilots accept this eventuality as an unlikely professional risk. Pilot confidence in their own superior training, skills and equipment contribute to this belief.

Pilot views differ slightly regarding the characteristics of an optimum helmet. In conjunction with an evaluation of three lightweight helmets undergoing flight testing at Nellis AFB, Nevada, the author participated in the interviews of eight pilots on November 6-7, 1978. Pilot views of the optimum helmet were supported by the aforementioned beliefs and contributed to the rationale for their proposals. One view

refuted the need for crash or impact protection and preferred a lightweight device capable of supporting needed communication and oxygen equipment similar to World War II soft leather helmets. This option would provide the lightest possible weight, facilitate movement, visibility and promote comfort. The other view was somewhat supportive of the need for impact protection (related directly to aircraft egress) but insisted on the need for lightweight, comfort and a design that enhanced movement and visibility. A possible solution to this question can be found in an analysis of US Air Force accident data which provide a representative sample of actual experience.

ACCIDENT EXPERIENCE

The findings of two research projects provided an excellent sample involving both peacetime and combat accident experience. Both studies reaffirmed the need for head protection. Left unsolved was the question of the degree to which a helmet should provide protection or enhance mission accomplishment. The Lehman studys' purpose was to evaluate helmet retention and the incidence of head injury when the helmet was lost during ejection or extraction. (18:1) This study attributed the adoption of hard shell head protection to the increased number of head injuries caused by the introduction of ejection/extraction systems. The second study, by Dunham and Sissung, attempted to establish protective headgear requirements for the aircrews of all types of US Air Force aircraft based upon aircrew surveys, accident experience and escape procedures. (5:iii) The research subjectively analyzed a sample of the accident population between 1 January 1967 through 30 June 1970,

examining the head injuries of 123 aircrew members involved in 95 accidents. (5:28-29) They concluded that 67 crewmen (55%) required increased protection which, "... supports the need for using protective headgear." Figure 5 depicts a summary of that analysis.

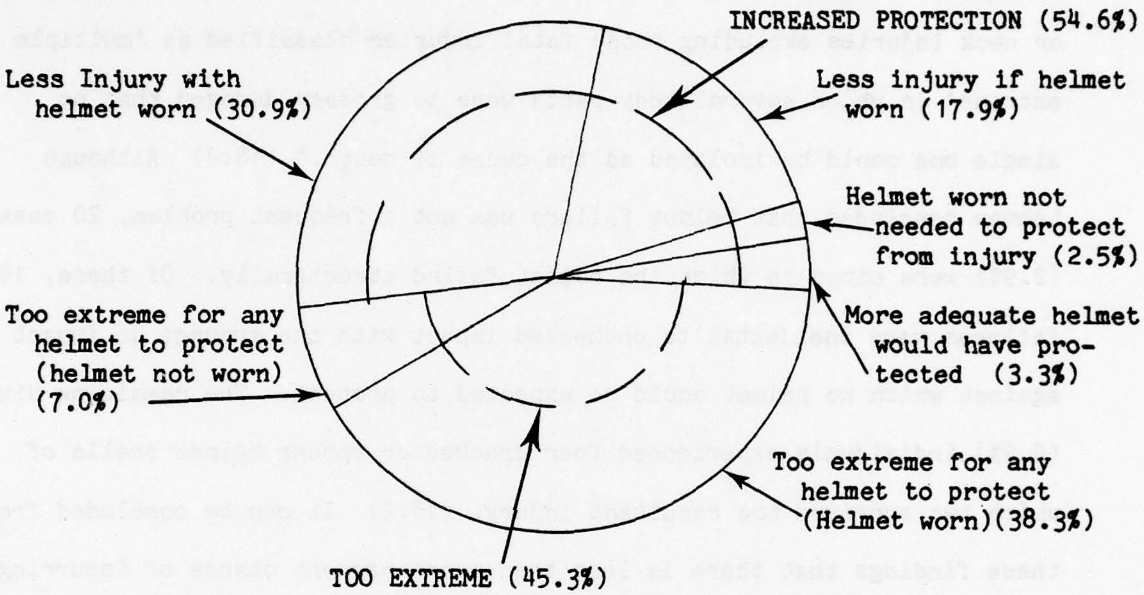

FIGURE 5. HEAD INJURIES RELATED TO HELMET ACCIDENT PROTECTION (5:29)

The Dunham and Sissung and Lehman projects provided supportive data on the frequency with which pilots have been exposed to head injury; an essential element in the determination of risk and the degree of protection required. Since these projects were somewhat different in purpose and scope, head injuries associated with aircraft escape by ejection or extraction were used as a common factor. The two studies evaluated 817 individuals involved in ejections and extractions from over 4,000 Air Force accidents between January 1967 and 31 December 1972. It should be noted that both studies included combat experience from Vietnam.

Lehmans' research into 682 Air Force ejections and extractions between 1 January 1968 and 31 December 1972 produced results which confirmed that head injuries were directly related to helmet retention. In addition, Lehman found that "... 84 (12.4%) individuals suffered head or neck injuries excluding those fatal injuries classified as 'multiple extreme' in which several body parts were so grossly damaged that no single one could be isolated as the cause of death." (18:2) Although Lehman concluded that helmet failure was not a frequent problem, 20 cases (2.9%) were cited in which the helmet failed structurally. Of these, 14 failures were incidental to unchecked impact with the ground; an impact against which no helmet could be expected to protect. The remaining six (0.9%) individuals experienced four cracked or sprung helmet shells of which two survived the resultant injury. (18:2) It can be concluded from these findings that there is less than a one percent chance of incurring a fatal head injury during ejection or extraction.

An analysis of the Dunham and Sissung research project produced similar conclusions. This project evaluated 316 accidents involving ejections and extractions in fighter/attack aircraft between January 1967 and 30 June 1970. (5:104-105) From the data presented, 76 of the 474 persons involved in these accidents were fatalities, of which 71 were other than head injuries. The remaining five (1.1%) were fatal head injuries and included four (0.8%) individuals whose helments functioned and one (0.2%) whose helmet failed. It may be assumed from these five cases that one helmet was incapable of protecting the individual from the impact of the blow; however, in the other four cases, the blow was insufficient to cause helmet structural failure. These data are summarized by Figure 6.

By eliminating the incongruity caused by the overlapping time periods in the data bases of the two studies, general conclusions concerning the total sample were possible. The combined data showed that of the 817 individuals involved in ejections between 1 January 1967 and 31 December 1972, five (0.6%) were fatally injured due to head injuries despite their protective headgear. In consideration of these facts, pilot preference for decreased protection to obtain lightweight and comfort is understandable.

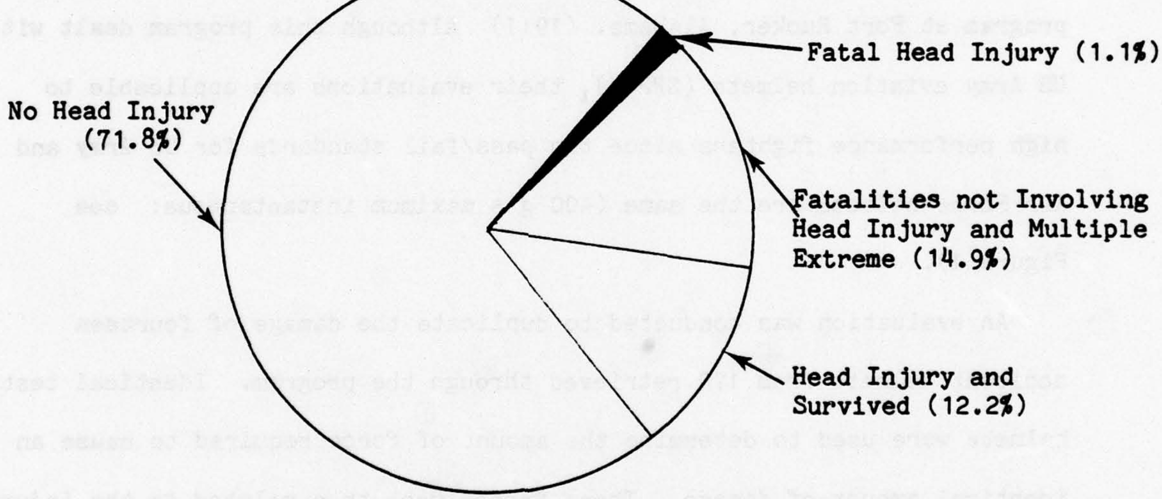

FIGURE 6. HEAD INJURIES RELATED TO HELMET PROTECTION IN EJECTION/EXTRACTION

The modification of the helmet penetration test criteria could significantly reduce weight by decreasing the thickness of the shell. This would permit an increase in protection by varying foam liner thickness to give greater impact protection.

The results of these studies and the service requirement that all pilots wear protective headgear support the need for hard-shell head

protection. Since leather helmets afford the wearer no protection from head injury, regardless of the probability of occurrence, their use would be imprudent when technology can produce a lightweight, hard-shell helmet capable of providing adequate protection, without sacrificing mission accomplishment.

HEAD IMPACT PROTECTION

Prior to 1972, little research was accomplished to determine the amount of force imparted to the helmets of accident victims. However in that year, the US Army established a life support equipment retrieval program at Fort Rucker, Alabama. (19:1) Although this program dealt with US Army aviation helmets (SPH-4), their evaluations are applicable to high performance fighters since the pass/fail standards for US Army and Air Force helmets are the same (400 g's maximum instantaneous: see Figure 1).

An evaluation was conducted to duplicate the damage of fourteen accident helmets from 170 retrieved through the program. Identical test helmets were used to determine the amount of force required to cause an identical amount of damage. These forces were then related to the injury of the victims. The results of the evaluation for eight of the fourteen helmets which resulted in head injury are shown below. (19:2-3)

TABLE 2

CASE	PEAK G	INJURY
13	73	Unconscious; - 2 min.
6	322	Basalar skull fracture; unconscious - 30 hrs.
14	355	Subdural hematoma; unconscious - 24 hrs.
8	316	Fracture of C,; unconscious - 2 min, semi-conscious-6 hrs.
5	141	Deep scalp laceration; dazed-several minutes.
7	263	Unconscious- several minutes.
1	184	Unconscious - 100 hrs.
4	415	Basal skull fracture w/sub-aracnoid hemorrage; FATAL.

Note the discrepancy between the injury and the peak acceleration g involved in cases fourteen and one. There is a strong implication that factors other than acceleration g account for the severity of a head injury.

The Army concluded from this data:

> "... that the pass-fail criterion currently used by the Army selects helmets for use by aircrewmen which for the most part prevent death in crash situations, but certainly do not prevent concussive head injury. Considering the potentially hostile post crash environment which can be experienced by an Army aircrewman such as fire, drowning, and capture, the injury level permitted by the current pass-fail criterion is unacceptable." (19:3)

Based on these findings the Aeromedical Research Laboratory at Fort Rucker, Alabama proposed two alternative methods of determining aircrew helmet impact attenuation. The two methods, termed Severity Index (SI) and Head Injury Criterion (HIC) involved the calculation of impact force on the helmet over time and established a concussive threshold of 1,500 and 1,000 respectively. (19:3-5) Since the findings in the above table showed no correlation between the magnitude of the impact and the

resultant injury, the only remaining variable was the amount of time the impact force exerted itself on the helmet. Applying the concussive thresholds of SI and HIC to the eight cases, five of the eight helmets were eliminated leaving cases 13, 5 and 1 remaining. Had SI or HIC standards been applied to the accident helmets before they were accepted by the Army, only three of the above accidents might have resulted in head injury. The remaining helmets would have been rejected since they could not attenuate sufficient force to pass the SI or HIC standards.

The Human Tolerance Curve method was recommended by the Dunham and Sissung study. (5:3-4) The curve related impact energy to time and the distance over which energy was disipated to determine resultant force. Their recommendation was based on the conclusion that it was unrealistic to test helmets by criteria in which the test fixtures, headform and impacting surfaces were absorbing part of the energy. (5:57) The mathematical formulas for each of the above methods (SI, HIC, and Human Tolerance Curve) are at Appendix II.

Impact standards that consider time in the determination of resultant force have been a part of the American National Standards Institute (ANSI Z-90.1A) standards for vehicle users since 1973. (See Figure 1) Recently, the US Navy adopted the above ANSI Z-90.1A standards in their military specifications for the HGU-34/P helmet. (23:5)

Although the above facts give confidence to the established limit of human head impact tolerance (400 g), and the ability of existing helmets to meet these criteria, there is no evidence to support a weight reduction due to the possible decrease in protection. However, recent research by the US Army Areomedical Research Laboratory, Fort Rucker,

Alabama, into increasing energy absorption without a corresponding increase in weight has been encouraging. Although the test reports deal with the US Army SPH-4 helmet, the technology used is applicable to any design. A description of four of the twelve test helmets are shown below. (17:1)

TABLE 3

Type	Outer Shell Thickness	Outer Shell Material	Foam Thickness (Inches)	Foam Liner Density (lbs/ft^3)
IX	.020 - .042	KEVLAR, 2 Ply	.735 - .790	3.50 - 3.86
X	.018 - .047	"	.50	3.20 - 3.40
XI	.020 - .052	"	.750	3.20 - 3.40
XII	.017 - .042	"	.88	3.27 - 3.46

The helmets were tested using a rigid anvil with flat and hemispheric impactors. Since the foam area crushed by the impact of a hemispheric anvil has approximately a two inch radius, and the foam normally crushed from most accidents is much wider, the hemispheric anvil used during ANSI Z-90.1A testing was considered excessive (17:1). As a result, tests were predominantly conducted using a flat anvil as well as a representative number of tests using a hemispheric anvil for comparison purposes. Since Haley and Turnbow previously established the increased energy absorption capability of double-shell construction, (24:2) helmets using that construction technique were used exclusively in these tests. (17:1) The drop weight of the headform without the helmet was 10.75 pounds. Drop height varied from 36 to 80 inches dependent on impact location. (17:2) Assuming the helmet shell and liner together weighed no more than one

pound, the impact force varied from 35.75 - 77.55 foot pounds. A facsimile of Haley and Turnbows' study results, by helmet type, are shown below. (17:2)

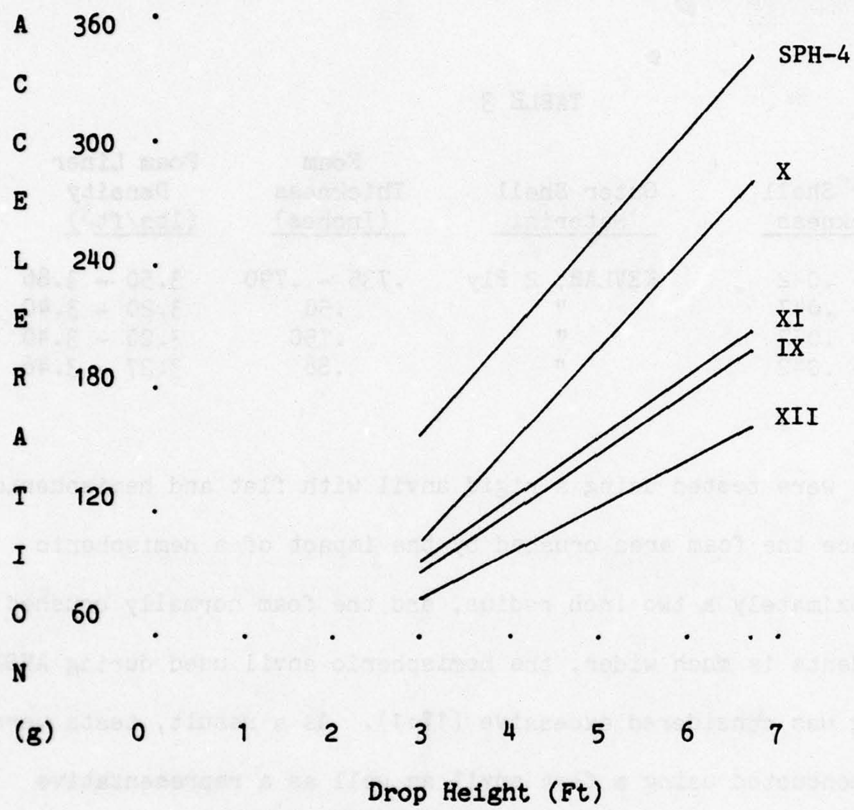

FIGURE 7: PEAK ACCELERATION VERSUS DROP HEIGHT

Analysis of Table 3 and Figure 7 show that for impacts on flat surfaces, variations in shell thickness and foam density result in an eleven to sixty percent reduction in forces when compared to the SPH-4. (17:2) The tests found that shell thickness had little effect when tested against flat surfaces; however, when tested against a hemispheric anvil, shell thickness was significant. A thicker shell prevented the foam liner from compressing and transmitting high acceleration forces to the head.

Conversely, a thinner shell required a corresponding increase in liner thickness to achieve the same level of protection. (17:2) The report concluded, "... a helmet that can attenuate impact energy at a lower peak acceleration level will significantly reduce the number of concussion type head injuries in survivable helicopter accidents." (17:2)

The continuing efforts of the U.S. Army Aeromedical Research Laboratory and Mr. Joseph L. Haley and his staff have indicated that light weight and protection are compatible and currently producible. Based upon discussions with the author, Mr. Haley views the existing problems surrounding the procurement of a lightweight helmet to be twofold.

First, existing penetration standards are incompatible with impact standards. The incidence of a pointed object penetrating a helmet such as a bullet or projectile against which no helmet could provide protection is very low. Yet, existing penetration standards require that shell thickness remain high to guard against this eventuality.

Second, existing standards ensure that no manufacturer will attempt to market a helmet with a paper-thin shell. Since the US Air Force authors its own specifications for helmet manufacture, Mr. Haley believes the penetration standards are expendable in lieu of a stipulation in the specification concerning shell thickness, strength and stiffness. In addition, Mr. Haley indicated that elimination of the current penetration standards would free industry to produce a helmet and liner capable of attenuating impact forces sufficiently to reduce the impact standards from 400g to approximately 150g without increasing weight. This would mean an increase in protection 2.6 times greater than existing impact

standards, and eliminate from consideration those helmets that exceed the concussive threshold or experience peak acceleration in excess of 150 g.

In view of pilot accident experience, the US Army Aeromedical Research Laboratory's claims for more impact protection with reduced weight, the elimination of existing penetration standards are justifiable. In addition, continued research into the proper combination of shell and liner thickness indicates that shell thickness can be reduced and protection improved if the liner thickness remains a minimum of one inch. In an attempt by industry to produce an acceptable lightweight helmet, a number of innovative alternatives have been attempted.

RECENT APPROACHES TO WEIGHT REDUCTION

In May 1977, Tactical Air Command (TAC) provided industry with a Statement of Work for developing future high performance fighter aircrew helmets. The statement adopted the ANSI Z90.1A standards for impact protection but lowered the drop height to reduce the impact force from 100 to 35 foot pounds which would accomodate the manufacture of a lighter helmet. (20:7) The weight requirement for this helmet, including the shell, liner, communications equipment, visor and retention systems were not to exceed 2.25 pounds. (20:14) In addition, the statement sought a design that would offer modular protective features for laser, flash blindness and chemical warfare contingencies as well as exhibit light weight, comfort, unrestricted vision, communications, high stability and protection. (20:1-3) Exclusive of the modular (hang-on) features, the statement of work clearly correlated reduced weight with decreased impact standards but the penetration requirement was maintained at the 1968

standard. (See Figure 2) (20:7) Tactical Air Command's approach has not maximized the most relevant protective qualities of helmets. As a result, TAC may have jeopardized the safety of their pilots since contemporary research, accident experience and test analysis clearly show that impact protection should be increased rather than decreased. Additionally, there is a compelling argument for the deletion of penetration standards since accident experience does not justify its retention and it hampers development of an optimum lightweight helmet.

New innovations by industry portray significant weight reductions. In May 1976, Sierra Engineering Co. produced a lightweight prototype that contained a number of innovative features. Helmet weight was reduced to 2.39 pounds (mean of test helmets) by reducing the weight of the shell and liner to 0.78 pounds. (21:3-4) The overall weight of the helmet, exclusive of visor and visor housing was reduced to 0.86 pounds by installing a communications transducer behind the nape strap and using plastic tubes to lightweight earphones fitted into form fitted silicone earcups. This feature, which is similar to the earphones used on commercial airliners, resulted in a 43.7 percent decrease in communications weight from the existing plastic earphones. (21:5-6) As a result of these communications improvements, the silhouette of the helmet was reduced which contributed to weight reduction. The impact force was reduced by the Air Force to 60 foot pounds and the ANSI Z90.1A standards were applied. Penetration tests were conducted using 1968 USAF Military Specification standards. All helmets passed the impact and penetration tests by a substantial margin. (21:33-35) Exclusive of the oxygen mask

receptacles and helmet retention system, the remaining 1.53 pounds (2.39 - 0.86) was largely consumed by the helmet visor assembly.

In response to the weight contained in the visor assembly, a number of other prototypes have eliminated the visor housing. The helmets evaluated at Nellis AFB, Nevada, November 6-7, 1978, in which the author participated, utilized a visor that snapped on to the helmet shell and lay flush against the edgeroll of the liner. All of the test helmets utilized existing communication earcups and oxygen mask receptacles, yet the weight for each helmet was approximately two pounds.

CHAPTER IV

CONCLUSIONS

The development of a lightweight helmet for high performance fighter aircrews is a highly technical and complex task. Attempts by industry to produce lightweight helmets that meet Air Force specifications have repeatedly encountered problems due to the interrelated features of comfort, retention, visibility, noise attenuation, weight and protection. Dichotomies in the specifications, contradictory standards and the often conflicting desires of the aircrews versus command guidance have further frustrated the realization of a suitable lightweight helmet. Despite this frustration, continued research into protective helmet technology as well as the adoption of innovative weight reduction measures have produced encouraging results.

A lightweight helmet is currently achievable without sacrificing protection. In fact, protection can apparently be increased while reducing overall helmet weight (e.g., shell, liner, communication and retention systems, and oxygen mask recepticles). To accomplish this, penetration standards must be deleted from existing specifications. Accident statistics have repeatedly shown numerous researchers that objects rarely penetrate pilot helmets. On those occasions when the helmet was penetrated, the magnitude of the impact (bullet/pointed object) was so great that no helmet could have provided protection. In view of these facts, the penetration standards can be justifiably deleted. Based upon accident investigations of helmet damage, most

impacts crush a wide areas of the foam liner - which argue convincingly for the need for more impact protection. This view is underscored by Lehman's research which showed that 55 percent of head injury victims needed additional protection. This may be accomplished by the services specifying the shell thickness strength and stiffness, with no specific penetration criteria. In this regard, if the impact test employed a flat anvil, a suitable test for shell strength could be that no breaking, cracking, or crushing occur as a result of the impact. In addition, the research conducted by the US Army Aeromedical Research Laboratory showed a significant increase in impact protection could be realized by considering the duration of an impact force, and by reducing the maximum transmitted force (g) to 150g to prevent unconsciousness. By deleting penetration standards and adopting the recent recommendations of contemporary research as well as innovations in communications, oxygen recepticles and visor housing, lightweight helmets can be produced that weigh no more than two pounds (large sizes 2.25 pounds).

Current US Air Force standards are vague and inconsistant. This creates ambiguities that result in helmets having dissimilar protective qualities. The US Navy has adopted most of the ANSI Z90.1A standards in an effort to standardize testing. However, the Air Force allows ambiguities to exist in the weight of the headform and the use of varying drop heights between swing away and rigid anvil test methods. These factors should be standardized to form a solid basis against which all helmet candidates can be judged. For example, existing Air Force standards penalize a heavy helmet because it is dropped from a standard height which results in a greater impact force than a light helmet. This

standard is ludicrous, because it forces a pilot with a large head to wear a heavier helmet (thicker, harder shell to absorb more energy) than needed to provide the same amount of protection. The alternative is to standardize headform weight and impact force (100 foot pounds) and allow drop height of the helmeted headform to vary to achieve that force. In this manner, all aircrews would receive the same level of protection with slight variations in weight due only to the size of the helmet - not the influence of the test.

The US Air Force is the principal user/operator of high performance fighter aircraft. Yet, the Air Force maintains no helmet retrieval program to determine the adequacy of helmet design standards. Such a program could have identified the questionable value of penetration standards and identified the important relationship between impact force and time long ago. Such a program is essential to identify adverse trends and helmet limitations.

RECOMMENDATIONS

1. Delete penetration criteria from MIL-H-83147 (USAF).

2. Adopt the rigid anvil (dropped) method of testing helmets for impact force attenuation.

3. Utilize a flat anvil during testing to determine impact force.

4. Modify the impact pass/fail standard to:

   a. Include in pass/fail criteria a provision that no crushing (soft spot), breaking or cracking of the shell occurs as a result of the impact.

   b. Adopt a criterion which considers the relationship of time and force similar to ANSI Z-90.1A criteria.

   c. Reduce maximum acceptable transmittal force from 400g to 150g.

5. Standardize the amount of force to which helmets will be subjected during impact testing at 134.84 J (100 foot pounds) and allow drop height to vary to achieve this force.

6. Standardize headform weight at 5.0 kg (11.1 pounds).

7. Establish maximum acceptable helmet weight including shell, liner, communication and retention systems, and visor at two (2.0) pounds. Large helmets should not exceed 2.25 pounds.

8. An accident helmet retrieval system be established by the US Air Force to ascertain the type and amount of force actually experienced by Air Force crewmembers. This data should be included in the Air Force Inspection and Safety Center computer library.

9. Adopt for use, feasible innovations in helmet equipment and design that reduce weight and enhance safety such as the communication system proposed by Sierra Engineering and the snap-on visor proposed by Protection Inc.

10. See Appendix 3 for proposed changes to MIL-H-83147 (USAF).

AREAS REQUIRING FURTHER RESEARCH

The research involved in this study revealed additional areas deserving further investigation. First, continued research into helmet retention systems and their alternatives is essential to reducing head injuries during ejection/extraction. Both Lehman and Sierra Engineering pointed out the necessity for helmet retention systems to enhance pilot survival.

Second, research into alternative communications systems that are both lightweight and miniaturized with high audio resolution will contribute to lighter helmets. Since there are many alternative systems available it is only a matter of choosing which system is most adaptable.

Third, methods to increase sound attenuation in helmet design should be pursued. Problems with the seal around the earcups continue to degrade sound attenuation and the use of eyeglasses further compounds this problem.

Fourth, existing visors create a potential hazard due to the lift generated by the housing during ejection. Recent prototype visors may be lost as soon as the canopy is jettisoned, exposing the face and eyes to severe windblast. Continued research into helmet visors and their alternatives must be avidly pursued to reduce the suns glare, act as a medium for training air-to-air weapons and enhance helmet retention qualities.

It must be kept in mind that comfort, above all, is the most important helmet characteristic to the pilot. Without comfort, the pilot can become distracted by pressure points in the liner, operate at decreased effectiveness due to annoyance, and may in extreme cases remove the helmet or abort the mission. When determining helmet design characteristics, this factor must receive first priority.

Further, there are many desirable features for protective helmets. Based on the authors research, those characteristics creating the most controversy are weight, retention, visibility and protection. However, these features are so interrelated that a piece of equipment though simple in appearance has in fact become a complicated system. Despite

this complication, new methods and materials must be developed to produce lightweight helmets that maximize protection against those hazards most likely to be encountered by jet fighter pilots. After all, the cost of on-going research and development into protective headgear can be justified when compared to the multimillion dollar investment in each pilot and aircraft.

APPENDIX I

APPENDIX I

DEFINITION OF TERMS

Foot-Pound: A unit of energy equal to the work done by raising one pound avoirdupois against the force of gravity the height of one foot.

Gravity (g): In physics, the gravitational acceleration of a body toward the center of the earth by centrifugal force. Its value is approximately equal to 980cm or 32.16 feet per second per second.

Joule (J): The energy equivalent to the work performed at the point of application of a force of one newton as it moves through one meter in the direction of the force.

Kinetic Energy (KE): A capacity for performing work. A mass may have energy based on position or motion. Energy of motion is known as kinetic energy and is given by: $KE = 1/2\ mv^2$.

Newton (N): The force that provides a mass of one kilogram with an acceleration of one meter per second per second.

APPENDIX II

APPENDIX II

FORMULAS

SEVERITY INDEX (SI): (22:4)

$$SI = \int A^{2.5}\, dt$$

A = Resultant acceleration (g)

d = Differential

t = time (sec)

Calculated by dividing the acceleration pulse into infinitely small time increments. Each time increment of value $A^{2.5}$, t is determined. By adding these values for the entire pulse, the Severity Index is determined. Pass-fail value is established at 1500.

HEAD INJURY CRITERION (HIC): (22:4)

$$HIC = \left[\frac{\int_{t_1}^{t_2} a . dt}{t_2 - t_1} \right]^{2.5} (t_2 - t_1)$$

t_1 = An arbitrary time in the pulse

t_2 = For a given t_1, a time in the pulse which maximizes

a = Resultant acceleration

All possible values of t, are calculated for an acceleration pulse from a given impact. The maximum value obtained is the HIC for that pulse. A value of 1000 is established as the concussive threshold.

HUMAN TOLERANCE LIMIT CURVE: (7:2-4)

$$a = \frac{2(S - v_i\, t)}{(t)^2}$$

a = Acceleration
v_i = Initial velocity
S = Distance
t = Time, pulse duration

If initial head impact velocity were 120 inches per second and stopping distance was one inch, the head would experience an average of 15 g's negative acceleration.

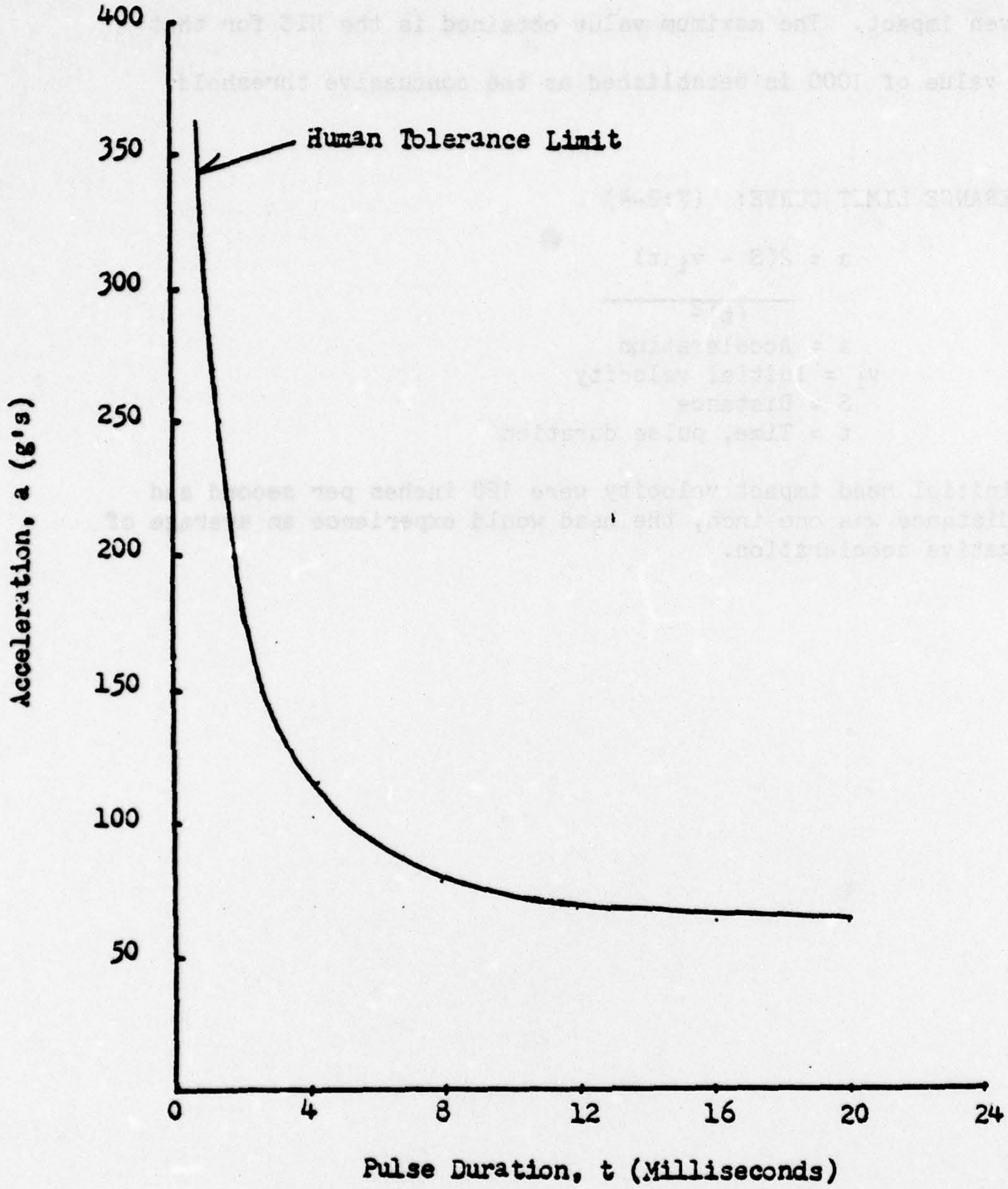

FIGURE 8: Human Head Impact Tolerance Limit Curve

APPENDIX III

APPENDIX III

RECOMMENDED CHANGES TO MIL-H-83147 (USAF)

24 June 1968

NOTE: Extensive use of a 12 April 1977 statement of work for industry was used to formulate this recommendation. (23:1-23)

Paragraph 3. Add a new subitem to read:

Weight. The weight of the aircrew helmet assembly shall be such that the helmet shell, liner, communications, visor lens, oxygen and helmet retention devices shall not exceed 2.0 pounds.

Paragraph 4. Quality Assurance Provisions. Change to read:

4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements and tests specified herein. The contractor shall submit for Government approval, a System Test Plan, Acceptance Test Procedure, Reliability/Maintainability Demonstration Plan, Environmental Test Plan, and Electromagnetic or EMI Compatibility Test Plan which shall contain tests and procedures for the aircrew helmet assembly in accordance with the requirements of this specification. The supplier may use his own or any other facilities suitable for the performance of the inspection requirements and tests specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections and tests set forth in the specification where such inspections and tests are deemed necessary to assure supplies and services conform to prescribed requirements.

4.1.1 Tests to be conducted by the procuring activity require that the supplier consider the test requirements, design the helmet assemblies accordingly, and perform limited testing to verify performances. Items which have been "worn out" in test by the supplier shall not be delivered to the procuring activity as usable contract items.

4.2 Classification of inspection. The examination and tests required by this specification shall be classified as follows:

a. Acceptance tests.

4.3 Test conditions.

4.3.1 Orientation. The helmet assembly shall function in a satisfactory manner regardless of orientation.

4.3.2 Helmet assembly. The term "helmet assembly" applies to the following possible configurations with each configuration to be subjected to the tests specified in 4.6:

a. Helmet assembly with single visor lens and oxygen delivery system.

b. Helmet assembly with chemical biological protective device and flashblindness protective device.

c. Helmet assembly with single visor lens and integrated oxygen delivery system/chemical biological protective device.

d. Helmet assembly with integrated oxygen delivery system/chemical biological protective device and flashblindness protective device.

4.4 Test equipment. The contractor shall fabricate the following items of test equipment:

4.4.1 Mold assembly capable of receiving foam materials conforming to 3.2.2.2, allowing for expansion thereof, and designed to permit formulation of foam liners in varying thicknesses, and configured to meet requirements of 3.2.1 and 3.2.1.1.

4.4.2 Impact test headform meeting requirements of ANSI Specification Z90.1-1971/Z90.1A-1973 but with cranial surface configuration suitable for test of helmet assembly layups.

4.4.3 Impact test headform meeting requirements of ANSI Specification Z90.1-1971/Z90.1A-1973, but with cranial surface identical to the 3HCL headform.

4.4.4 Mold shells suitable for pouring custom-fit liners for the 1 through 6 HCL headforms.

4.5 Acceptance tests. Acceptance tests shall consist of the following:

a. Sound attenuation.

b. Communications (intelligibility).

c. Subjective use (odor/comfort).

d. Vision/visor area.

e. Retention.

f. G-forces.

g. Impact energy attenuation.

h. Windblast.

i. Environmental testing.

4.6 Test methods.

4.6.1 Sound attenuation. The earcups shall be subjected to and meet the requirements specified in 4.6.3 of MIL-E-83425.

4.6.2 Communications (intelligibility). The microphone system shall score 70% correct or better (in noise conditions up to 100 db reference to .002 dynes/cm^2) with a trained crew of speakers and listeners utilizing the American Standards Association word test. These tests will be accomplished by the procuring activity.

4.6.3 Subjective use. Objectionable odors, tackiness and objectionable or detrimental performance characteristics of the helmet assembly shall be determined by subjective evaluation. The helmet assembly shall be used by human subjects at altitudes from ground level to 50,000 feet, at temperatures from -40°F to +160°F or any combination of such altitude and temperatures for periods up to 2 hours. Subjective use tests are tests to be conducted at the discretion of and by the procuring activity when the helmet assembly appears to have performance characteristics or other properties which might be detrimental or objectionable for human use.

4.6.4 Vision/visor area.

4.6.4.1 Visual field. The binocular visual field shall be determined using test subjects having a head size compatible with the specific helmet assembly being evaluated. Each size of the helmet assembly shall be subjected to visual field tests. These tests will be conducted by the procuring activity.

4.6.5 Retention. A tensile strength test of the helmet retention system shall be accomplished in accordance with paragraph 11 of ANSI Specification Z90.1-1971/Z90.1A-1973 except that the total load applied shall be 350 pounds.

4.6.6 G-forces.

4.6.6.1 Escape system G's. The helmet assembly when placed on a dummy or human test subject and tested using an acceleration facility shall function in accordance with the established requirements with applied acceleration in accordance with figure 1 during oxygen flow conditions. (If test subject used.) When the helmet assembly is under positive acceleration loading, it shall not show any evidence of malfunction or failure. This test shall be conducted by the procuring activity.

4.6.6.2 Sustained G's. The helmet assembly shall be placed on a dummy or human test subject and subjected to a sustained G force of 8 $+G_z$ for not less than 30 seconds using an acceleration facility. The helmet assembly shall remain stable on the head and shall not show any evidence of malfunction or failure. This test shall be accomplished by the procuring activity.

4.6.7 Impact tests. Impact tests shall be accomplished on the following:

a. Sectional layups. Sufficient testing shall be accomplished to ensure compliance with requirements of 3.3.

b. Helmet shell configured to the 3HCL headform.

Impact tests shall be performed on the above items in accordance with ANSI Specification Z90.1-1971/Z90.1A-1973 by the rigid anvil method using the flat impactor. The impact test headform described in 4.4.2 shall be utilized for tests of the sectional layups. The headform described in 4.4.3 shall be utilized in testing the helmet shell. The four impact sites on the sectional layups shall be separated by a minimum of 4 inches. The orientation of the helmeted headform with respect to the vertical axis of the impactor shall be such that the point of impact on helmet shell will be not less than one inch from the edge boundary of the energy absorbing liner. The helmet shall be subjected to a single impact only at the top frontal, back and each side locations. The helmet-headform off-set distance and sectional layup off-set distance shall be measured at each site and the total weight of the helmet-headform drop system obtained prior to test. Based on the system drop weight, the height of drop shall be determined to deliver 100 foot pounds impact energy. The following information shall be recorded on the test summary sheet for each of the test locations on a single helmet:

a. Test configuration drop weight.

b. Helmet-headform off-set distance - contractor shall measure thickness of liner and shell opposite all impact sites and record this data.

c. Drop height.

d. Impact velocity.

e. Impact energy.

f. Acceleration - time data as follows:

(1) peak acceleration.

(2) total time of pulse.

4.6.7.1 Test procedure. The test sample shall be weighted, the off-set distance measured, and the system drop height determined so that input energy for the test sites will be 100 foot pounds at each impact site.

4.6.8 Windblast. The helmet assembly shall be mounted on an appropriately instrumented test mannequin, properly restrained for ejection in an aircraft ejection seat, and exposed to a windblast of 450 + 20 KEAS. Rise time to peak velocity shall be 0.3 seconds with no dwell

at maximum velocity and decay to 200 knots in 3 seconds. The following seat attitudes (emerging into the airstream by raising the seat to simulate actual ejection, until it is fully exposed to the airstream or by directing the airstream accordingly) shall apply:

a. Fully exposed in line, with the ejection seat guide rails

b. 45° yaw to the right

c. 90° yaw to the left

d. 45° yaw to the left

e. 90° yaw to the right

f. 30° pitch forward

g. 30° pitch aft.

These tests will be accomplished by the procuring activity.

4.6.9 Environmental testing. The contractor shall conduct the following environmental tests in accordance with MIL-STD-130 and test procedures approved by the Government.

a. Humidity

b. Acceleration

c. Vibration

d. Shock - procedure III for crash safety

e. Rain

f. Dust

g. Fungus

h. Salt fog

4.6.16 Other testing. The contractor shall conduct all other tests in accordance with the approved test plans and critical item design specifications.

5. PREPARATION FOR DELIVERY.

5.1 Preservation and packaging. Preservation and packaging shall be in accordance with level C of FED-STD-102.

5.2 Packing. Packing shall be in accordance with level C of FED-STD-102.

5.3 Marking. Shipping containers shall be marked in accordance with MIL-STD-129.

6. NOTES.

6.1 Intended use. This helmet assembly is intended for use in high performance fighter/attack aircraft.

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BIBLIOGRAPHY

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INSTITUTION	U.S. AIR FORCE (15:1)	U.S. NAVY (16:1)	American Natn'l Standards Inst Snell Memorial Foundation(5:8)	British Standards (9:9)
STANDARD	MIL-H-83147: 1968	MIL-H-85047(AS): 1978	Z90.1A: 1973	BS2001: 1972
Method	Helmet fit to rigid headform and impacted with a free-fall spike. Depth of impact measured with 10 lb force applied to spike.	Helmet shell assembly impacted with a free-fall spike. Electrical resistance between spike and headform recorded.	Helmet with cradle maximally relaxed, placed on alloy headform and impacted with a spike. Electrical resistance spike to headform recorded.	Helmet placed on headform. Spike placed on helmet and impacted with a dropped weight. Depth of penetration recorded externally.
Headform	Alloy: Same as impact test.	Alloy: Same as impact test.	Standard headform covered by electrically conductive material.	Standard wooden headform as used in impact tests.
Impactor	.45kg (1 lb) 60° conical point. Hardness-60 Rockwells Point not less than .38mm (.015 in).	3kg (6.6 lb) with 38mm fall 60° conical point. Tip radius 0.5mm and hardness-60 Rockwells.	3kg (6.6 lb) with 38mm fall 60° conical point. Tip radius 0.5mm and hardness-60 Rockwells.	3kg (6.6 lb) with 40mm high 60° cone. Tip radius 0.5mm and hardness of 45-50 Rockwells.
Impact -Height	3m (10 ft)	3m (10 ft)	3m (10 ft)	1m (3.25 ft)
-Site	6: Once in each 60° sector.	Above reference plane. 2 impacts at least 3 in apart.	Above reference plane. (Two impacts at least 3 in apart, clear of previous impact sites.)	Above defined circumference.
-Energy	13J (9.6 ft lb)	88J (66 ft lb)	88J (66 ft lb)	29J (21.5 ft lb)
Conditioning	Same as impact test.	Same as impact test.	Same as impact test.	Same as for helmet giving worst impact response.
Pass/fail Standard	Penetration of shell greater than ¼ in is failure.	Helmet rejected if demonstrable electrical contact between spike and headform.	Helmet rejected if demonstrable electrical contact between spike and headform.	Distance between point of spike and shell must never be less than 5mm.

FIGURE 2: HELMET PENETRATION STANDARDS

INSTITUTION	U.S. AIR FORCE (15:1)	U.S. NAVY (16:1)	AMERICAN NATIONAL STANDARDS (ANSI) (5:8)			
STANDARD	MIL-H-83147: 1968	MIL-H-85047(AS): 1978	Z 90.1A: 1973			
APPLICATION	Aircrew Members	Aircrew Members	Vehicle Users, Army & Air Force Helmets			
METHOD	Dropped on Swing-away Headform	Dropped Headform	Dropped or Swing-away Headform			
HEADFORM	Alloy; sm, med, lg	Alloy; 5.0kg (11.1 lb)	Alloy; 5kg (11.1 lb)			
ANVIL	Hemispherical, 7.3kg (16.3 lb) 1.9 in Radius (48mm)	Hemispherical, 1.9 in Radius (48mm)	Flat or Hemispherical, 5kg (11.1 lb) 1.9 in Radius (48mm)			
IMPACT SITE	Front, Rear, both Sides	Above reference plane separated by 1/6th the circumference	Four sites at random above reference plane			
NUMBER OF IMPACTS	4 Once each site	4 Once each site	8 minimum: 4 w/each Anvil, 2 impacts to each site			
IMPACT DETAILS:			Dropped Headform		Swing-away Headform	
			Flat	Hemispheric	Flat	Hemispheric
DROP HEIGHT	1.83m (6.1 ft)	1.384m (4.54 ft)	1.83m (6.1 ft)	1.34m (4.5 ft)	4.43m (14.6 ft)	3.32m (10.9 ft)
KE OF IMPACT	134.84J (100 ft lb)	68J (50 ft lb)	89J (66 ft lb)	68J (50 ft lb)	217J (160 ft lb)	163J (120 ft lb)
CONDITIONING	Ambient, Hot	Ambient	Ambient, Hot, Cold, Water Soak			
PASS/FAIL STANDARD	Not more than 19.6kn (400g) or bottoming evidence	Not more than 19.6kn (400g), or more than 9.8kn (200g) for more than 2 msec, or more than 7.4kn (150g) for more than 4 msec	Not more than 19.6kn (400g), or more than 9.8kn (200g) for more than 2 msec, or more than 7.4kn (150g) for more than 4 msec			

NOTES:

* 4.95kg (11.0 lb) Headform size used to form basis for comparison.

SNELL MEMORIAL FOUNDATION (9:6)		NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION (9:7)		BRITISH STANDARDS (9:5)	
1970		Federal Motor Vehicle Safety Std No. 218		BS 2001 - 1972	
Protective Headgear		Motor Vehicle Users		Motor Cyclists	
Dropped Headform		Dropped Headform		Fixed or Swing-away Headform	
Alloy; 5kg (11.1 lb)		Alloy; 4 sizes 3.5-6kg (7.8-13.4 lb)		Wood; 16 sizes	
Flat or Hemispherical 1.9 in Radius (48mm)		Flat or Hemispherical 1.9 in Radius (48mm)		Flat Wood: 5kg (11.1 lb)	
4 sites at random above reference plane		4 sites at random above test line, separated by at least 1/6th of maximum circumference		Front and rear on defined circumference - fixed headform on defined circumference or crown - Swing-away headform	
8 minimum: 4 w/each anvil 2 impacts to each site		8: 4 w/each anvil 2 impacts to each site		1 (see below $)	
Either Anvil		*Flat Anvil	Hemispherical Anvil	Fixed	Swing-away
1st Impact 2.44m (8 ft) 119J (88 ft lb)	2nd Impact 1.83m (6.1 ft) 89J (66 ft lb)	1.83m (6.1 ft) 89J (66 ft lb)	1.36m (4.54 ft) 67.7J (50 ft lb)	2.5m (8.3 ft) 123J (91 ft lb)	$2.5\left(\frac{K+1}{K}\right)M$ (K = Mass of Helmet Headform ÷ Mass of Striker) 123J (91 ft lb)
Ambient, Hot, Cold Water Soak		Ambient, Hot, Cold, Water Soak		Hot, Cold, Wet Spray	
Not more than 14.7kn (300g)		Not more than 19.6kn (400g), or more than 9.8kn (200g) (cumluative), or more than 7.4kn (150g) for more than 4 msec (cumulative)		Not more than 19.6kn (400g) $Impact repeated at same site if shell fractures	

FIGURE 1: HELMET IMPACT STANDARDS